Human-in-the-Loop Assessment of an En Route Trajectory Negotiation Concept

Nancy Smith, Paul Lee, Tom Prevot,
Everett Palmer, Vernol Battiste, Walter Johnson

NASA Ames Human Factors Division

Overview & Summary

- Two complementary studies conducted to assess Distributed Air-Ground Traffic Management (DAG-TM) trajectory negotiation concept
- DAG-TM 2002 study of CE-6 (and CE-5, CE-11)
  - Comparison with a baseline that mimics current day operations
  - Results indicate benefits potential:
    - Increased throughput, reduced inter-arrival variability, workload redistribution, more efficient altitudes flown, when compared to baseline
- DAG-TM 2003 study of CE-6
  - Comparison of pilot-initiated requests via voice vs. CPDLC
  - Comparison with Pre-DAG baseline (2015 operations)
  - Controller and pilot displays/tools significantly improved
    - DSR-emulation for the controllers
    - 3-D flight deck displays for the pilots
  - Results:
    - Feasibility and acceptability of trajectory negotiation concept & procedures
    - Overwhelming user support of CPDLC transfer of communications
    - Increased effectiveness of DSTs when integrated with CPDLC
- Conclusions and Recommendations

DAG-TM Background:

- Focus area of Advanced Air Transportation Technologies Project
- Research activities at Ames, Glenn and Langley Research Centers
- NASA Ames activities include air-ground concept simulation and evaluation in Airspace Operations Laboratory (AOL) and Flight Deck Display Research Laboratory (FDDRL)

NASA Ames Goals for Integrated Air-Ground Simulations:

- Evaluate 3 key DAG-TM "concept elements" for managing en route and arrival traffic by comparison to a baseline condition:
  - **CE-6:** "trajectory oriented" concept with new air-ground tools & procedures
  - **CE-5:** CE-6 operations with "free maneuvering" aircraft in traffic mix
  - **CE-11:** Self-spacing operations in TRACON airspace
  - **Baseline** (2002): Current-day operations with time-based metering
  - **Baseline** (2003): ~2015 technology (CPDLC comm transfer, some DSTs)
- Get pilot & controller feedback about prototype DAG-TM concept implementation
- Support elaboration and refinement of DAG-TM concepts, tools and procedures
- Begin to assess benefits, feasibility of DAG-TM concepts

- *Problem:*
  - Potential traffic separation conflicts may cause controller-issued deviations that are conservative or not preferred by users
  - Users may not always be able to fly preferred trajectories
- *Solution:*
  - Users and controller negotiate trajectory change requests
  - User-controller data exchange (intent, winds) for improved trajectory prediction
  - Controller uses enhanced DSTs integrated with data link:

    (conflict detection & resolution, trial planning, time-based metering, advisories)
  - ATC moves to a "trajectory-based" orientation

Automation-Supported Trajectory Negotiation Concept

Flight crew may use route planning tools to construct conflict-free, user-preferred routes. Route changes are downlinked to ATC for approval.

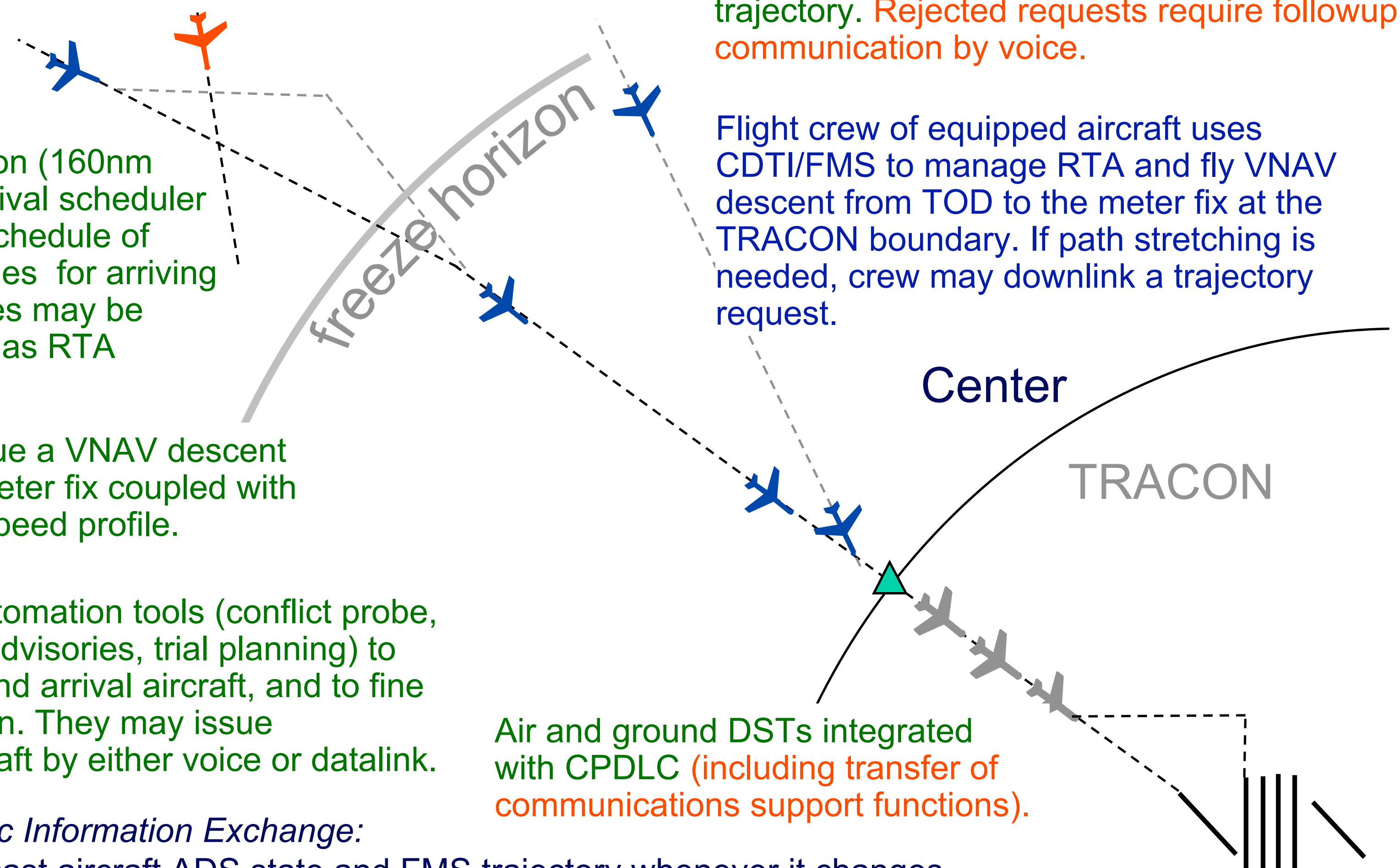
At the freeze horizon (160nm from meter fix), Arrival scheduler generates a final schedule of meter fix arrival times for arriving aircraft. These times may be uplinked to aircraft as RTA clearances.

Controller may issue a VNAV descent clearance to the meter fix coupled with either an RTA or speed profile.

Controllers use automation tools (conflict probe, timeline, descent advisories, trial planning) to monitor en route and arrival aircraft, and to fine tune the arrival plan. They may issue clearances to aircraft by either voice or datalink.

Controller uses trial planning tools to review downlinked requests. If acceptable, uplink response clears aircraft to fly requested trajectory. Rejected requests require followup communication by voice.

Flight crew of equipped aircraft uses CDTI/FMS to manage RTA and fly VNAV descent from TOD to the meter fix at the TRACON boundary. If path stretching is needed, crew may downlink a trajectory request.



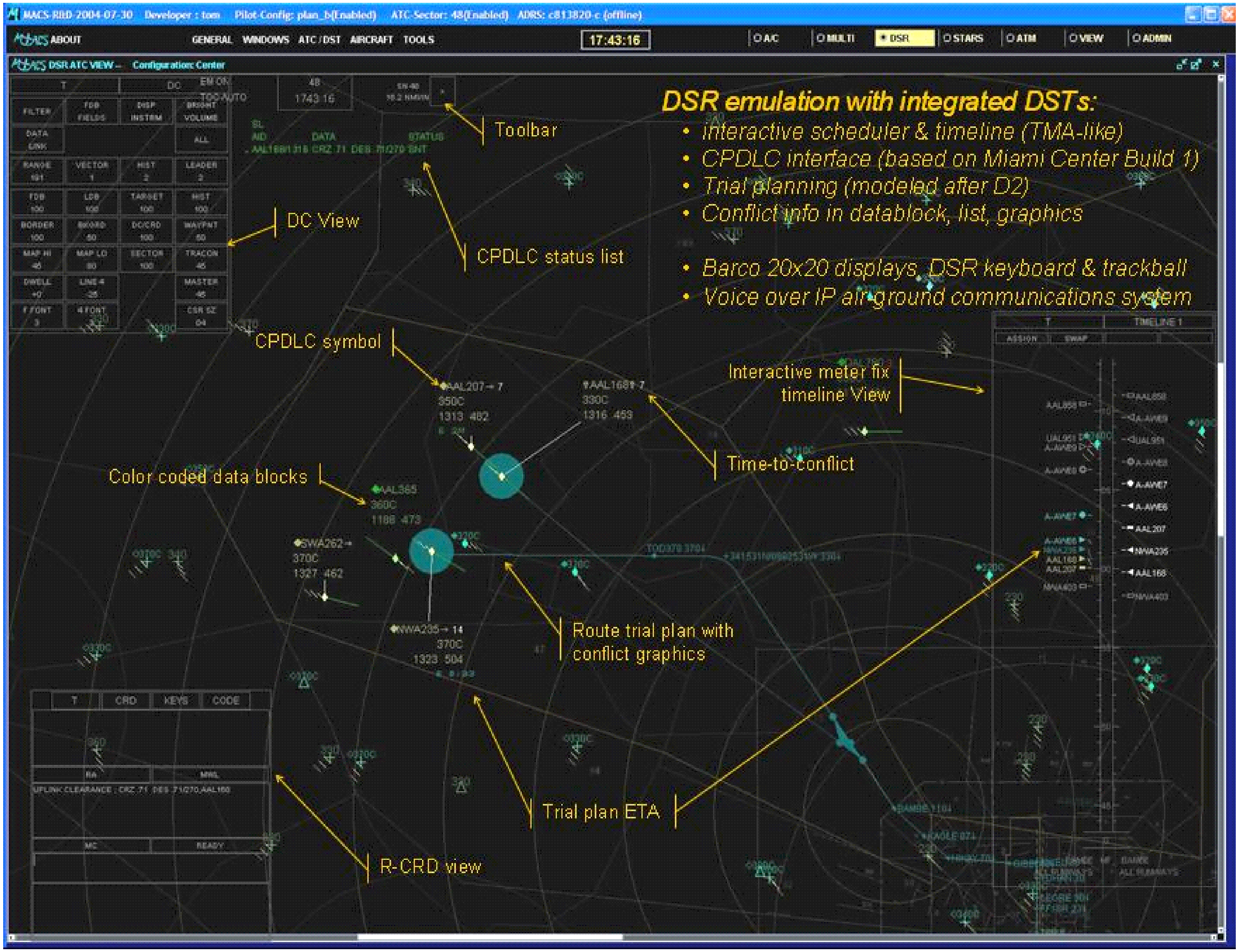
Air and ground DSTs integrated with CPDLC (including transfer of communications support functions).

Automatic Information Exchange:

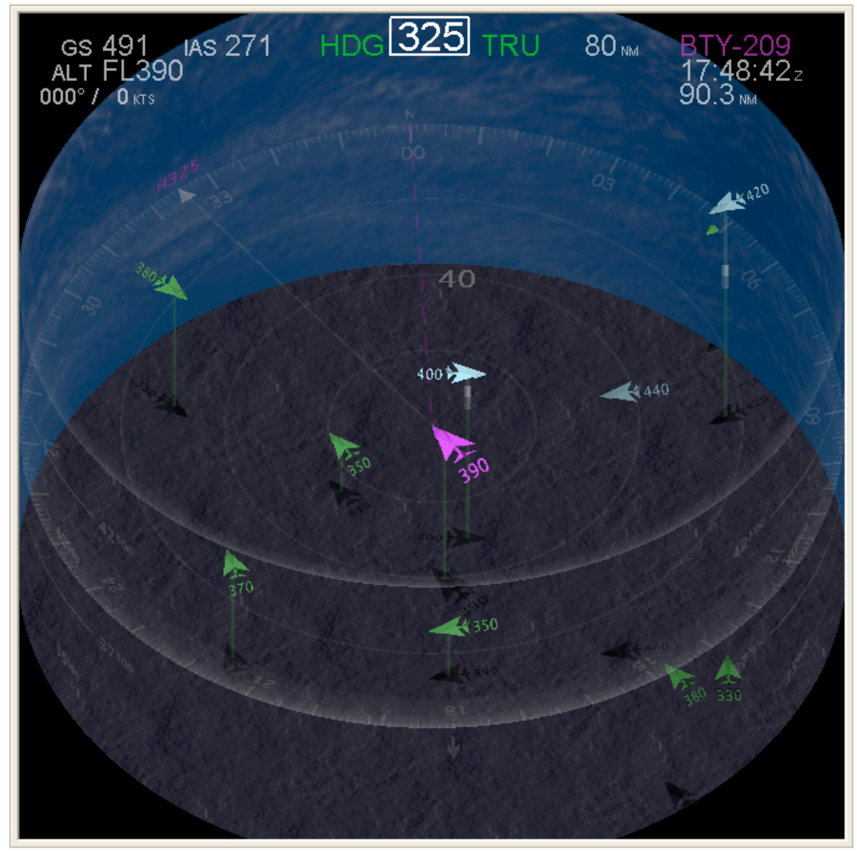
- Broadcast aircraft ADS state and FMS trajectory whenever it changes.
- Uplink forecast winds to minimize differences in air and ground trajectory computations.
- Uplink TMA meter fix times (RTAs or STAs).

- **Controller Tools:**
  - Meter fix scheduler (timeline)
  - ATC trial planning tool
  - ATC conflict predictor
  - CPDLC integrated DST operations
    - Clearance generation
    - Request evaluation
    - Transfer of communication
- **Communications:**
  - ADS-B (broadcast state information)
  - CPDLC for transfer of communications
  - CPDLC for clearance uplinks
  - CPDLC for downlink requests
- **Flight Deck Tools:**
  - CDTI of aircraft state & intent
  - RTA conformance capability
  - Route assessment tool (RAT)
  - CD&R for active and planned routes
  - CPDLC integrated DST operations
    - Request generation
    - Clearance evaluation
    - Clearance execution
- **Air-Ground Procedures:**
  - RTA clearance
  - VNAV Precision Descent clearance
  - Negotiation Procedure

DSR-emulation Controller Display (2003)



3-D Cockpit Display of Traffic Information

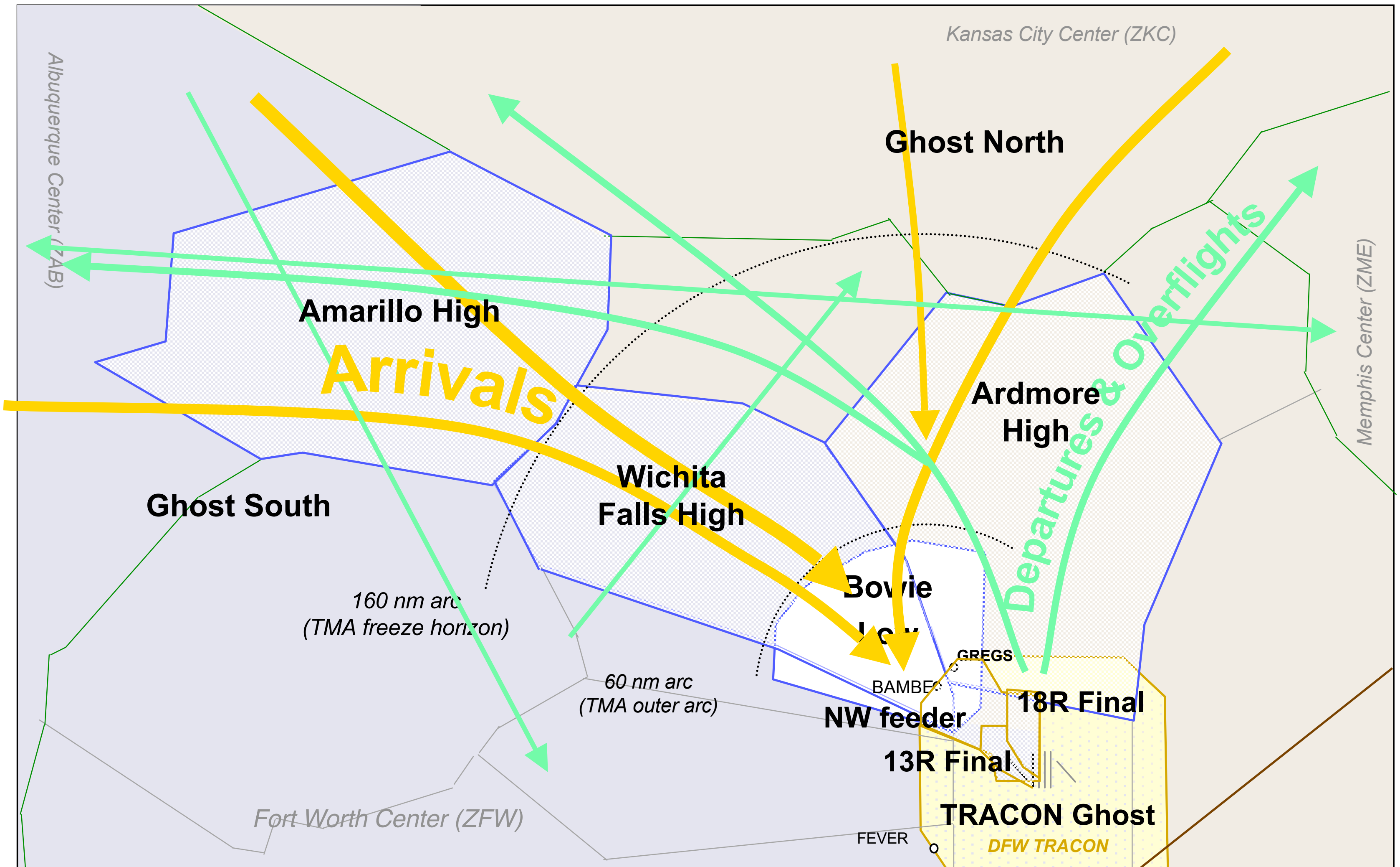


Purpose of Integrated Air-Ground Simulations

- *Goal:*
  - Evaluate DAG-TM “CE-6” concept: “Trajectory Negotiation for User-preferred Separation Assurance and Local TFM Conformance”

- *Approach:*
  - Develop an integrated prototype of air-ground simulation of concept.
  - Run multi-sector, moderate traffic problems with participant pilots and controllers
  - Compare operations in different tool environments.
  - Get pilot & controller feedback about concept performance
  - Record quantitative data to look for observable differences in outcomes (e.g., workload, actual routes flown, arrival time accuracy…)

"DAG" Airspace



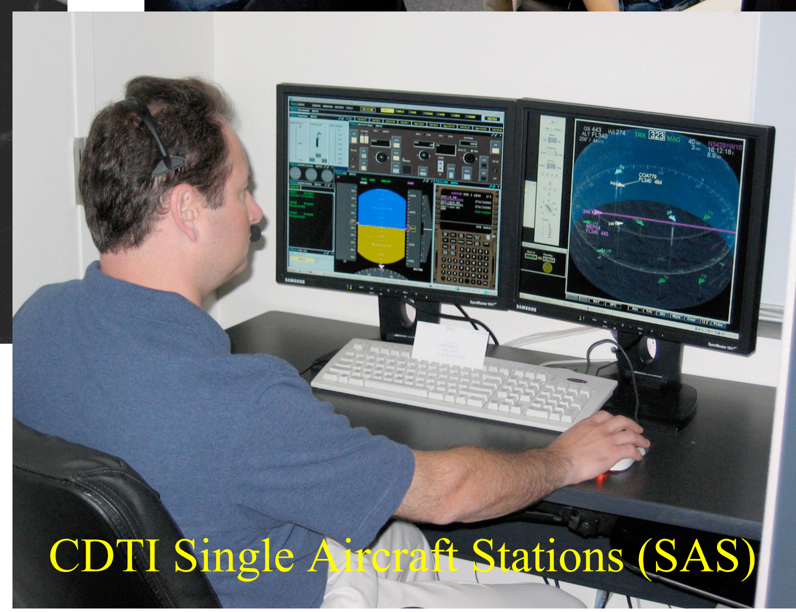
NASA Ames Airspace Operations Laboratory (AOL)

TRACON Control Room

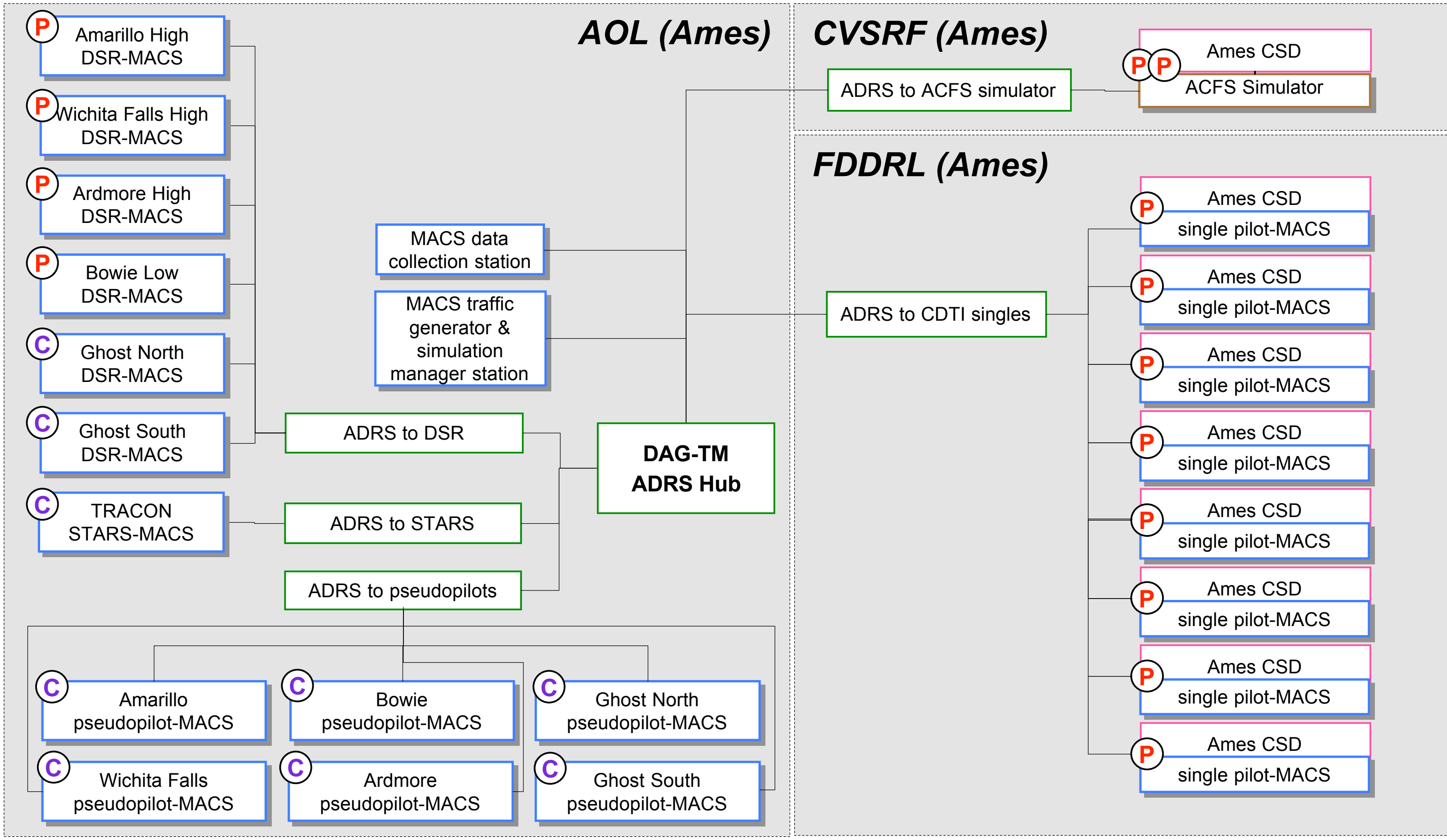
En Route (Center) Control Room

"Pseudo-pilot" Room

CDTI Single-pilot and Crew Stations



DAG-TM Simulation Infrastructure for 2003 CE-6 Experiment



Simulation Facilities:

CVSRF	*Crew-Vehicle Systems Research Facility*
FDDRL	*Flight Deck Display Research Laboratory*
AOL	*Airspace Operations Laboratory*

Processes:

ACFS	Advanced Concepts Flight Simulator
ADRS	Aeronautical Datalink and Radar Simulator
CSD	Cockpit Situation Display
DSR	Display System Replacement
MACS	Multi Aircraft Control System
STARS	Standard Terminal Automation Replacement System

Simulation Facility

operator station

process

P Participant

C Cohort

Experimental Focus for 2 Simulations

- **September 2002: <u>Benefits</u>**
  - Efficiency
    - Flight time
    - Flight distance
    - Altitude
  - Predictability / Quality of arrival flow
    - Arrival spacing
    - Arrival delivery accuracy
  - Workload impact and redistribution
- **November 2003: <u>Operational Feasibility</u>**
  - Acceptability to pilots and controllers
  - Tool usability and effectiveness
  - Procedures
  - Roles & responsibilities

DAG-TM 2002 Experiment – Test Plan

- Purpose
  - Compare 2 en route concepts — free maneuvering & trajectory negotiation to baseline
  - Compare TRACON concept — in trail self-spacing to baseline
- Controllers
  - 4 FPL en route, 1 TRACON & 3 'cohort' controllers
- Pilots
  - 6 commercial airline pilots flying CDTI-equipped PC-based aircraft simulators
  - 2 commercial airline pilots flying CDTI-equipped full-mission flight deck simulator
  - 7 'cohort' pilots flying PC-based multi-aircraft simulator workstations
- Traffic Scenario
  - 3 equivalent scenarios
  - ~ 90 aircraft including 45 arrivals from the west and north arriving at the northwest ZFW cornerpost within approximately 1 hour
- Exp Design
  - (Center) 3 test conditions
  - (TRACON) 2 test conditions

2002: Conditions & tools

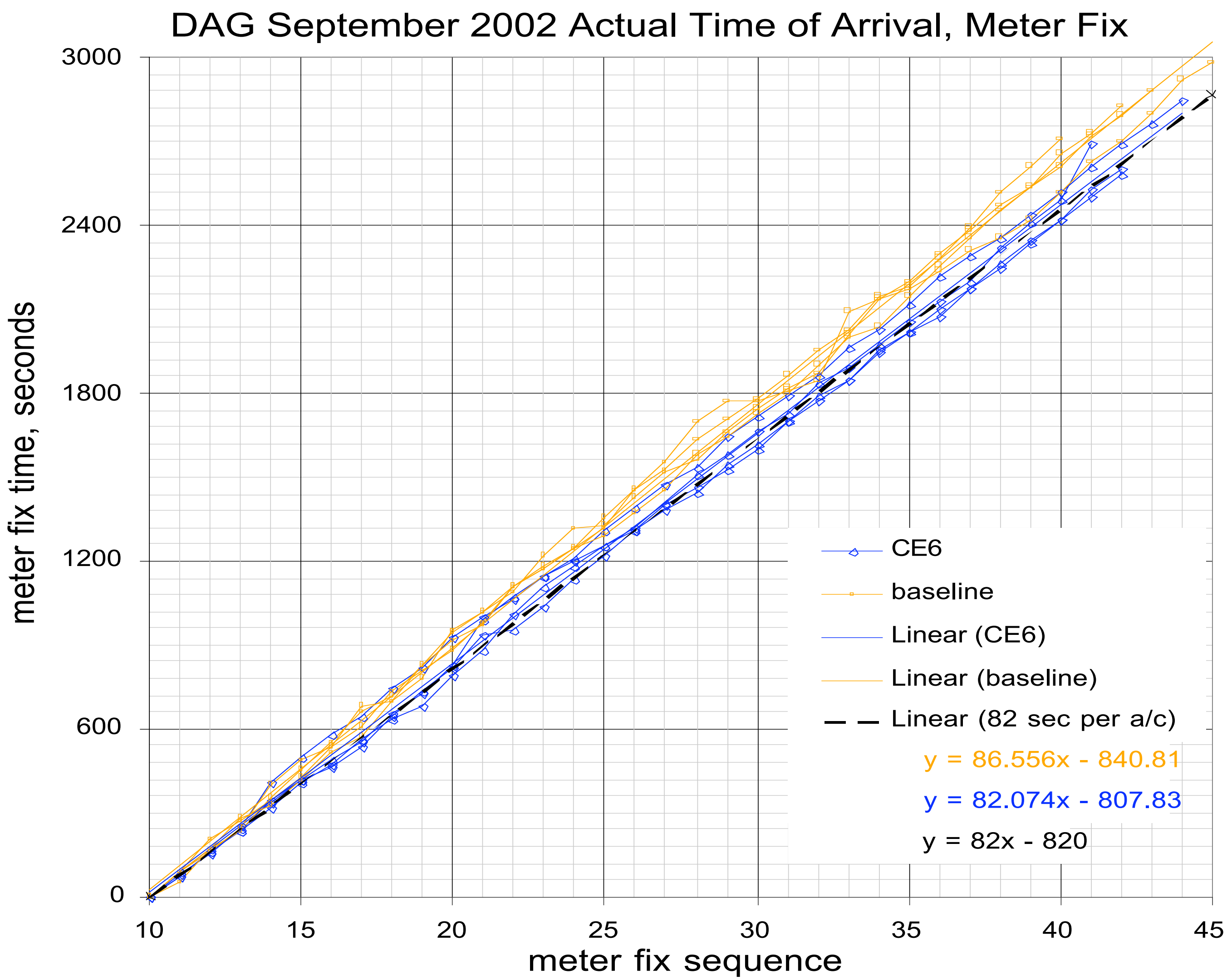
	Tools, capabilities and procedures	Current day ops.	CE-6
communication	ADS-B (broadcast state information)	x	x
	CPDLC for transfer of communications	-	-
	CPDLC for clearance uplinks		x
	CPDLC for downlink requests		x
ATC tools	Meter fix scheduler (timeline)	x	x
	ATC trial planning tool		x
	ATC conflict predictor		x
Cockpit tools	Flight deck CDTI of aircraft state & intent	x	x
	RTA conformance capability		x
	Flight deck RAT (route assessment tool)		x
	Flight deck CD&R		
procs.	RTA clearance		x
	"Precision Descent" clearance		x
	Negotiation procedure	-	-

DAG 2002 Results Summary

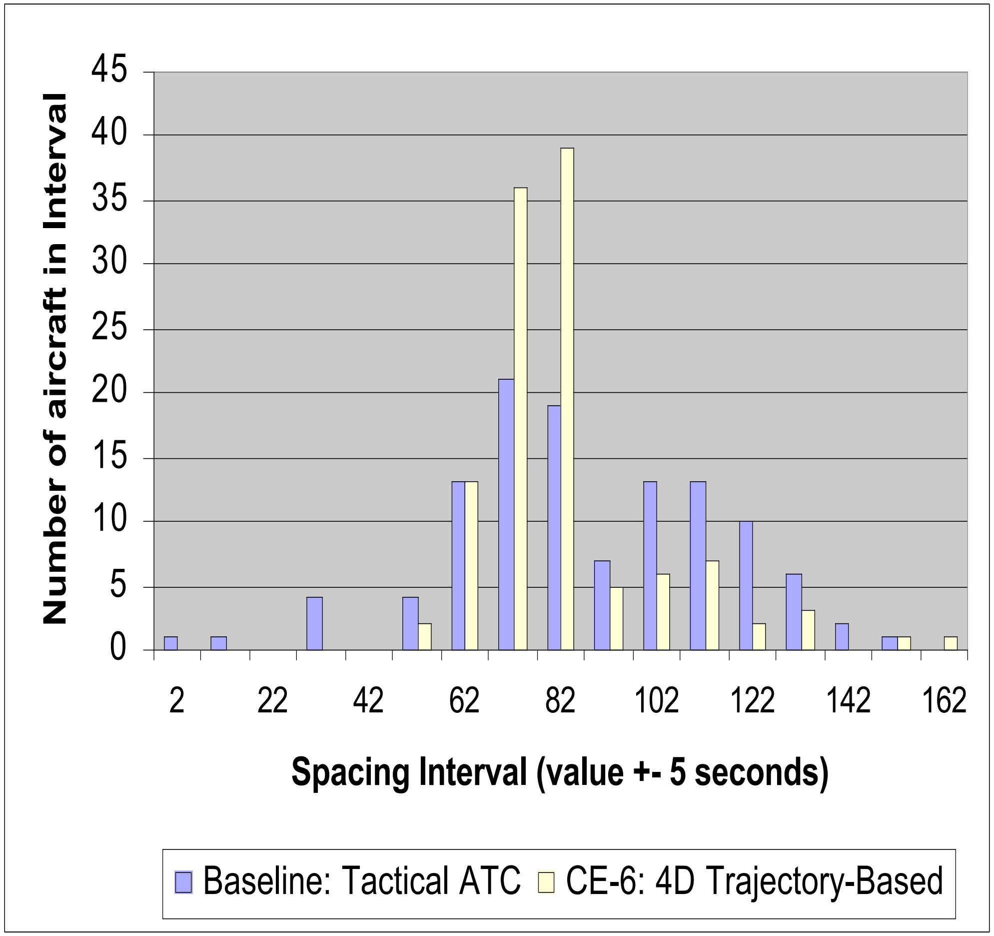
- Benefits compared to current-day baseline
  - Efficient flight path
    - Shorter flight time, shorter flight distance, higher mean altitude
  - Predictability / Quality of arrival flow
    - More consistent arrival spacing
    - More accurate arrival delivery
  - Increased meter fix throughput
  - Redistributed workload due to trajectory-oriented metering
    - Lower workload for downstream sector controller without increased workload for upstream sector controllers

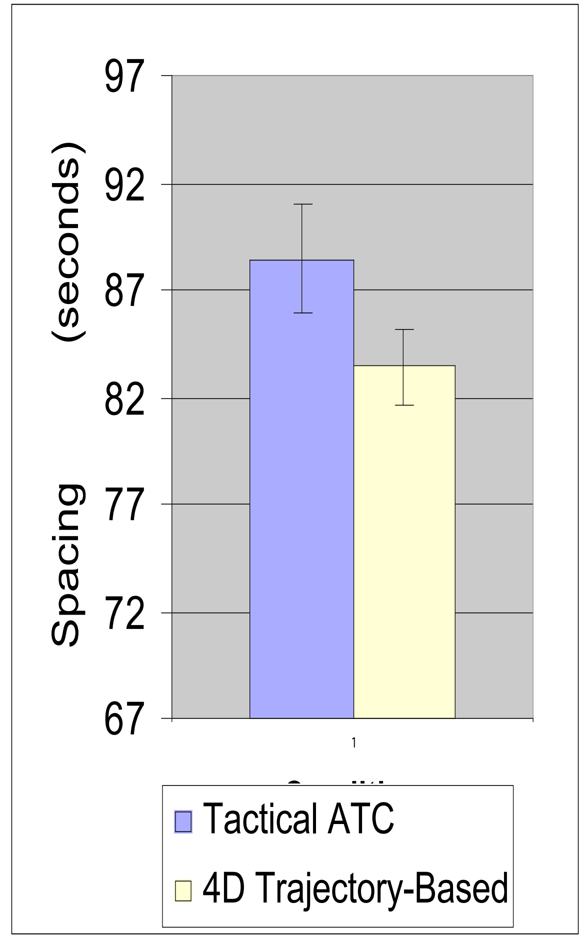
…With no increase in operational errors.

2002 Results: Meter Fix Throughput

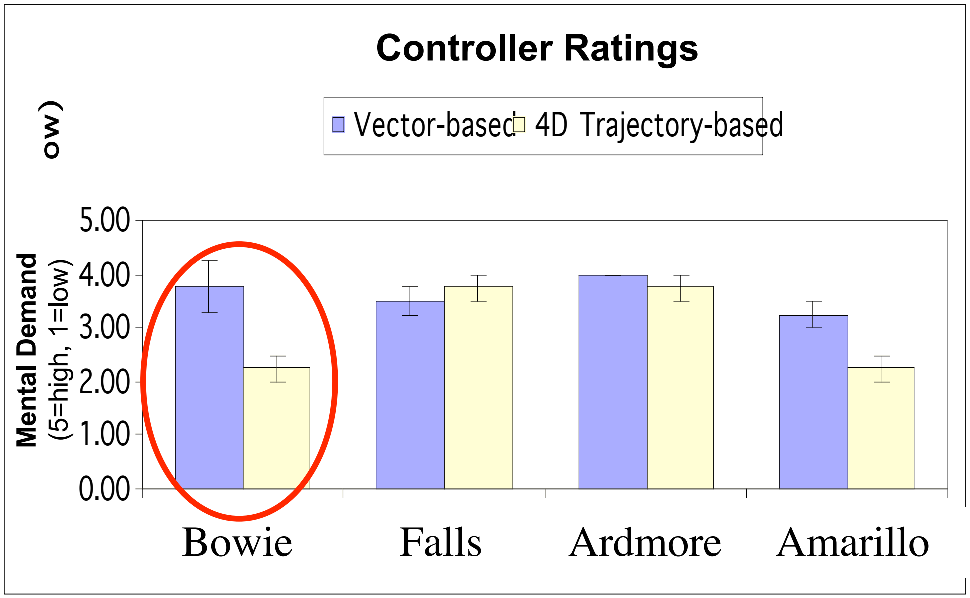


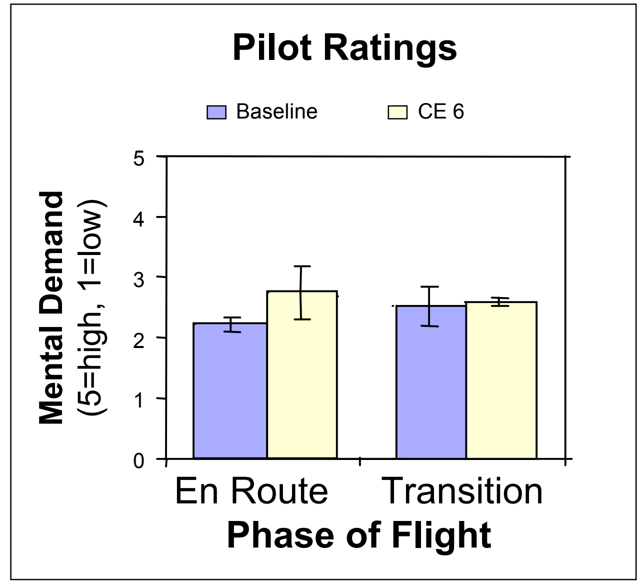
2002 Results: Arrival Spacing

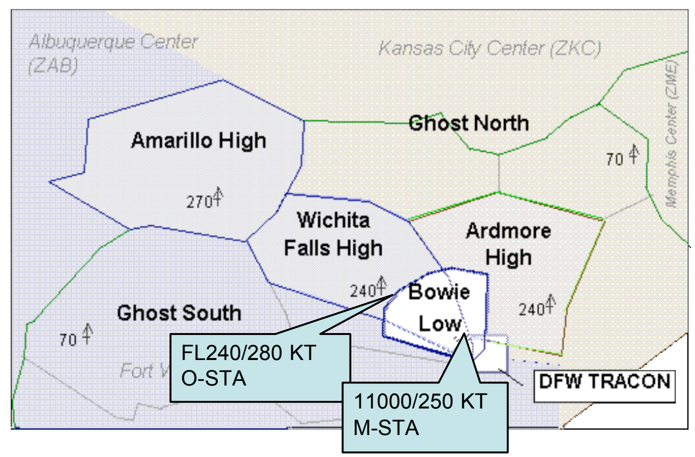




2002 Results: Workload







The low altitude controller (BOWIE) reported the greatest benefit from the trajectory-based operations

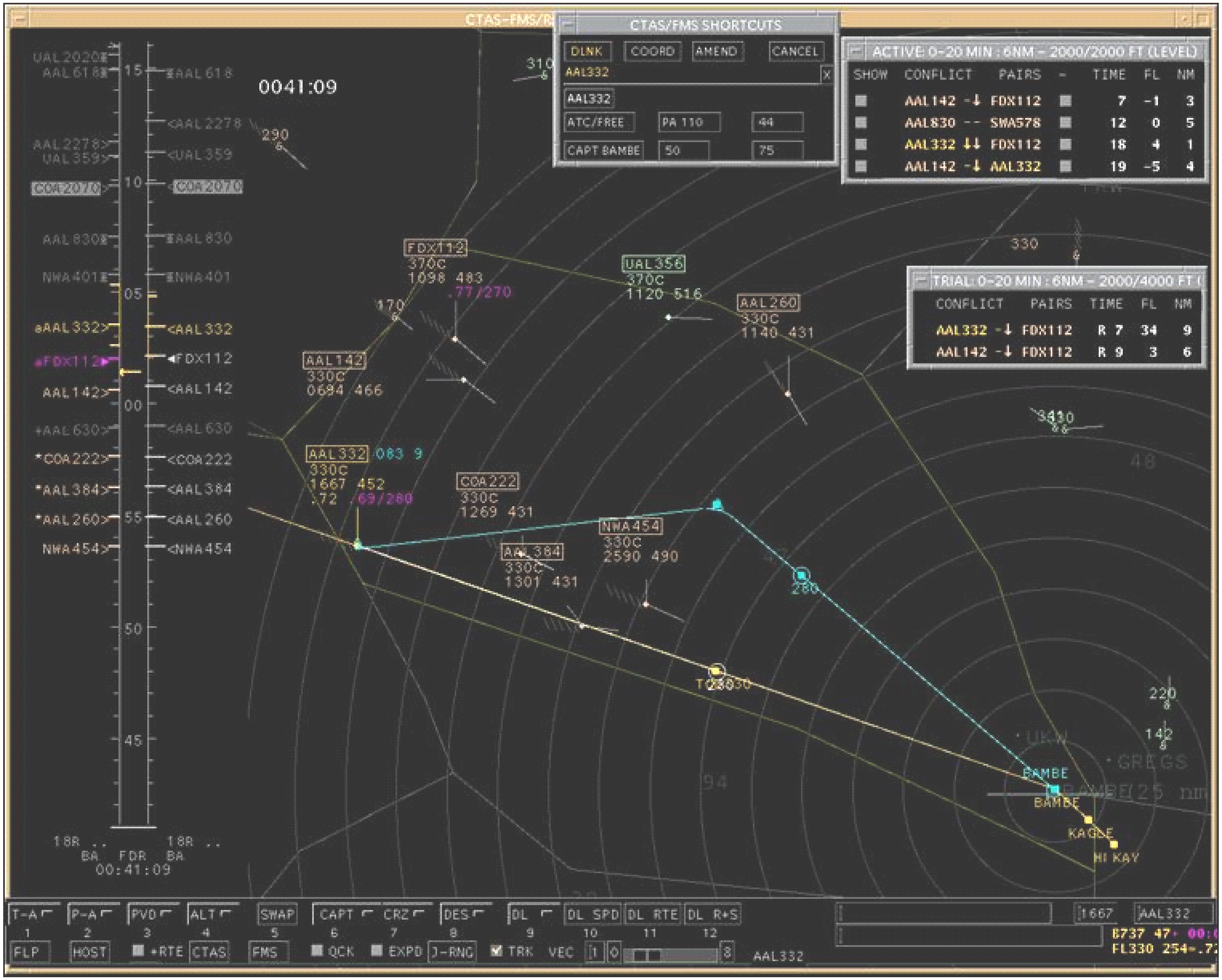
Air-Ground CE-6 Simulation: Fall 2003

- In DAG 2002 study, scenarios did not create enough incentive for downlink trajectory requests
- CE-6 2003 study
  - Re-assessment of trajectory negotiation concept
  - New scenarios with situations designed to elicit pilot-initiated requests
- Improved DST capabilities
  - New DSR-like controller display, faster trial planning, improved tool interface
  - Improved flight deck tools
  - Implement CPDLC supported transfer of communications
- Compare impact of supporting technology on trajectory negotiation

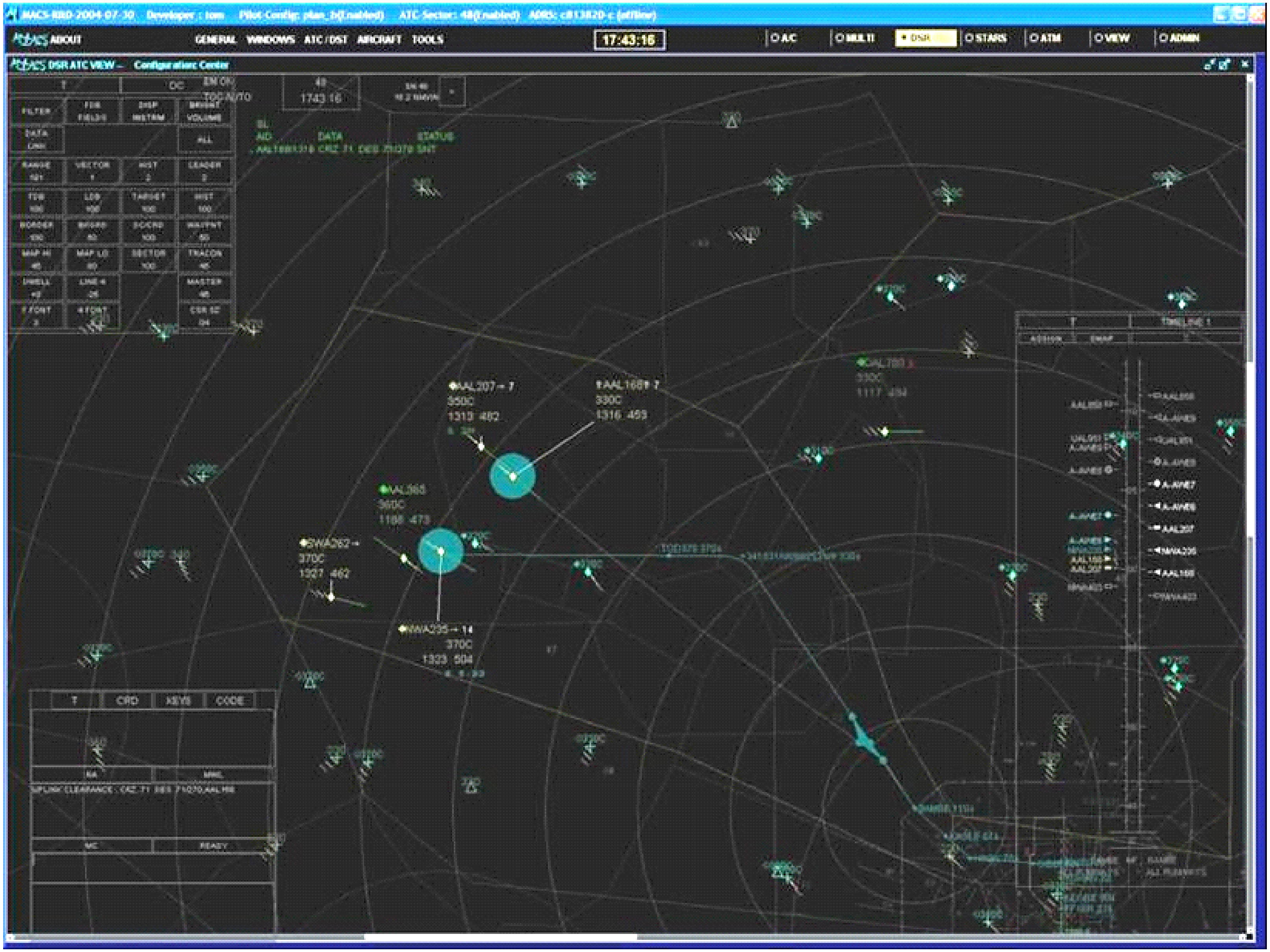
November 2003 Test Plan

- Controllers:
  - 4 en route certified professional controllers (CPCs)
  - 2 TRACON CPCs
  - 3 ‘cohort’ controllers
- Pilots:
  - 8 commercial airline pilots flying CDTI-equipped PC-based simulators
  - 2 commercial airline pilots flying CDTI-equipped full-mission simulator
  - 8 ‘pseudo’ pilots flying PC-based multi-aircraft simulator workstations
- Scenarios:
  - Participant pilots request flight path change in every run.
- Compare pre-DAG baseline to 3 CE-6 conditions:
  1) (Baseline) CPDLC for transfer of communications
  2) 1 + CPDLC for clearance uplinks only
  3) 2 + CPDLC trajectory request downlink capability
  4) 3 + flight deck CD&R to enable conflict free requests

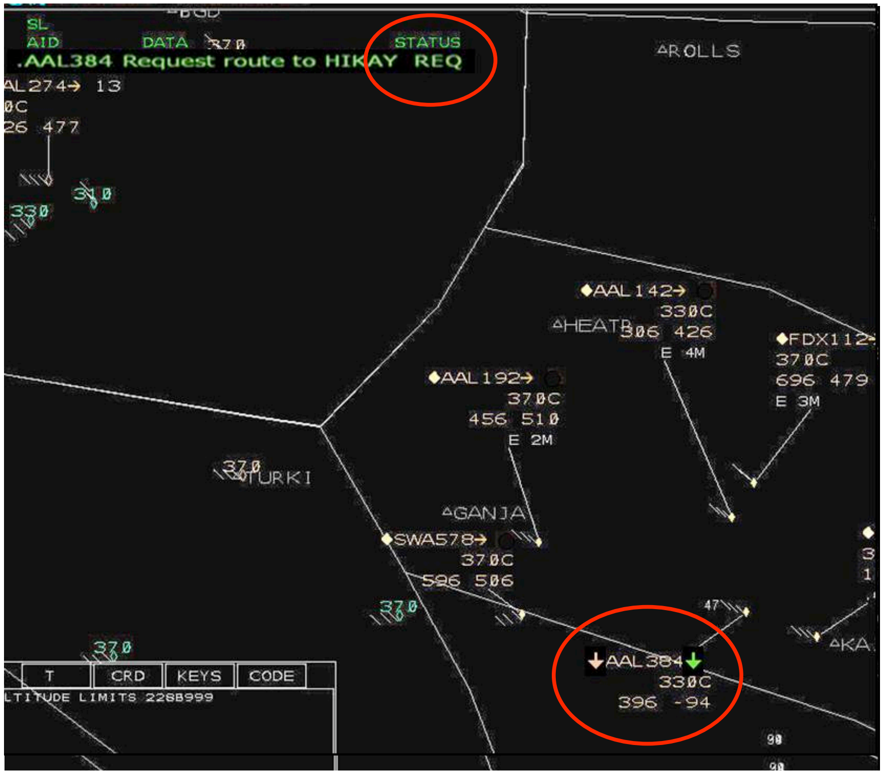
DAG-TM CTAS CE-6 display (2002)

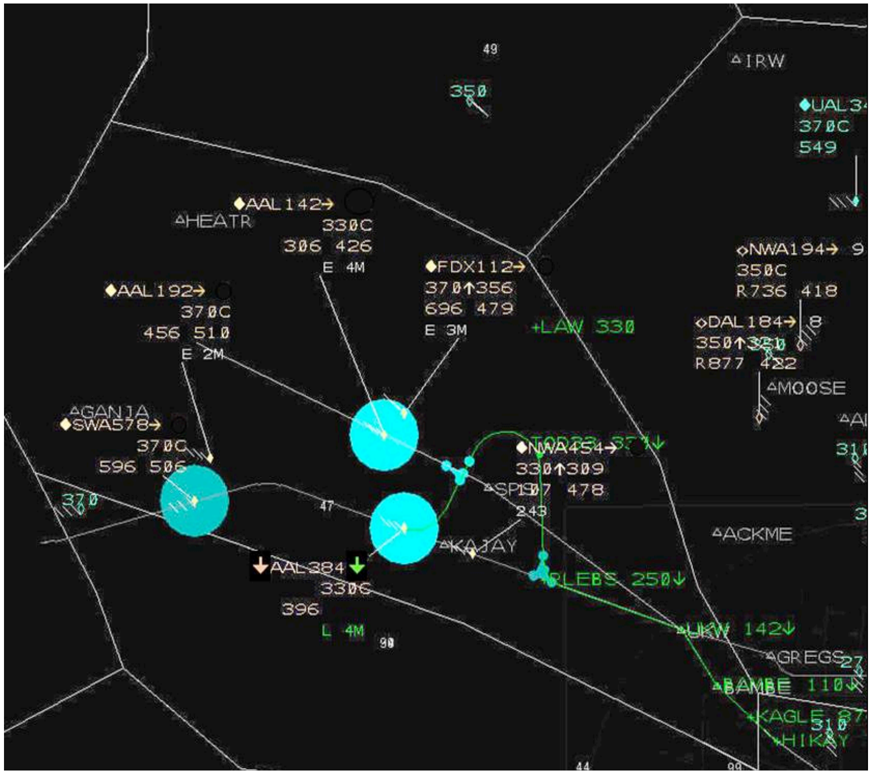


DSR-emulation Controller Display



Pilot-initiated Route Request



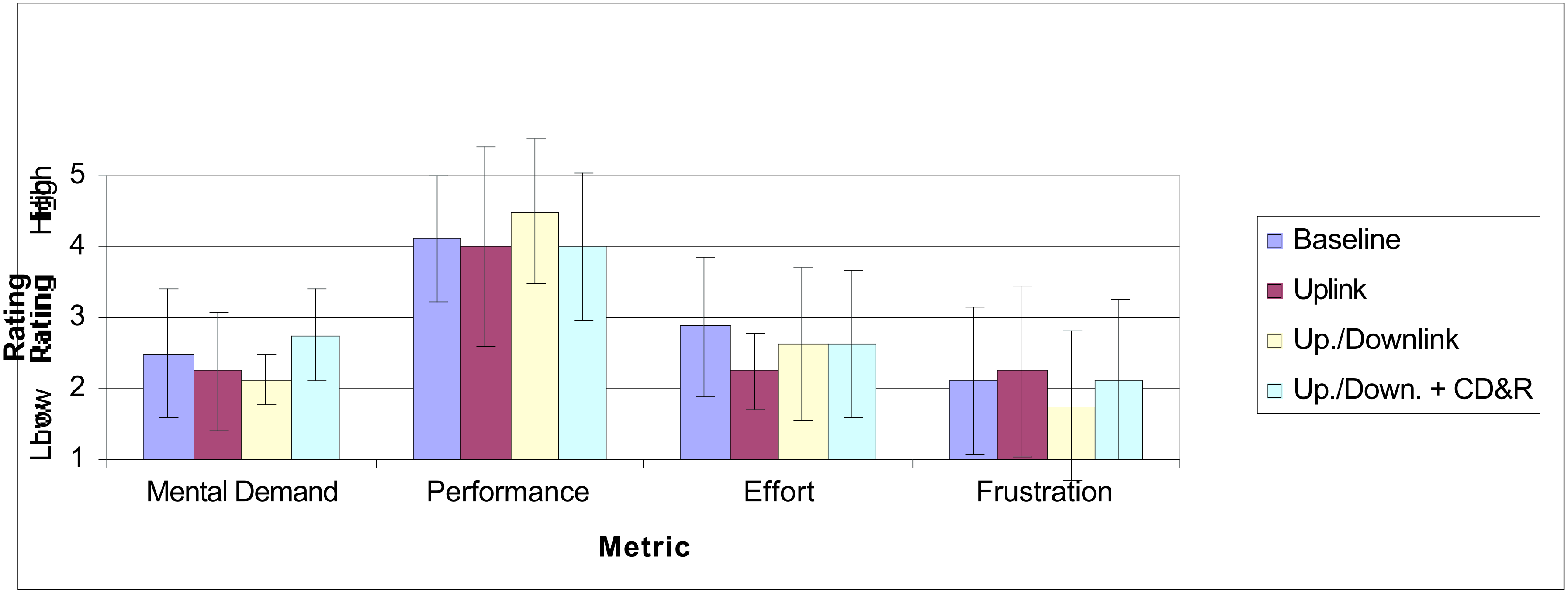


1. Ground automation has received a request from AAL384.
2. Cues are status list entry in upper left corner and down arrows beside call sign in datablock.
3. The snapshot on the right shows the requested route

2003: Conditions & tools

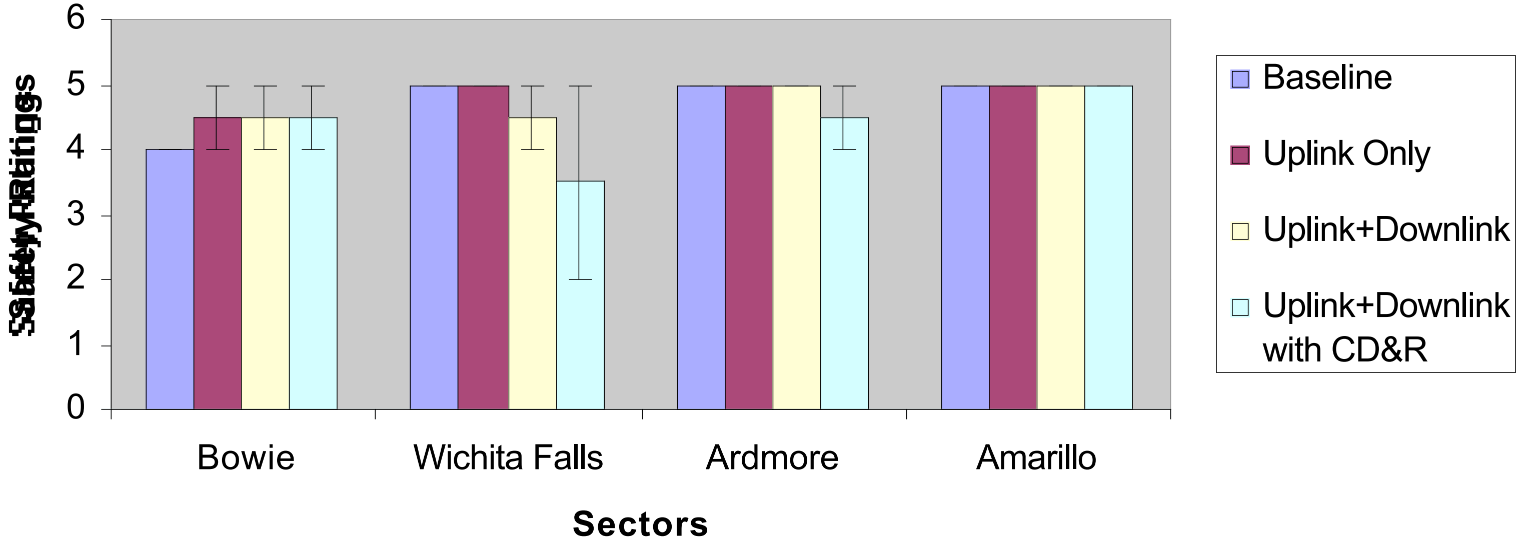
Tools, capabilities and procedures	Current day ops.	Uplink only	Uplink & downlink (1)	Uplink & downlink (2)
ADS-B (broadcast state information)	x	x	x	x
CPDLC for transfer of communications	x	x	x	x
CPDLC for clearance uplinks		x	x	x
CPDLC for downlink requests			x	x
Meter fix scheduler (timeline)	x	x	x	x
ATC trial planning tool		x	x	x
ATC conflict predictor		x	x	x
Flight deck CDTI of aircraft state & intent	x	x	x	x
RTA conformance capability		x	x	x
Flight deck RAT (route assessment tool)			x	x
Flight deck CD&R				x
RTA clearance		x	x	x
"Precision Descent" clearance	x	x	x	x
Trajectory Negotiation Procedure	x	x	x	x

2003 Results: Controller Workload



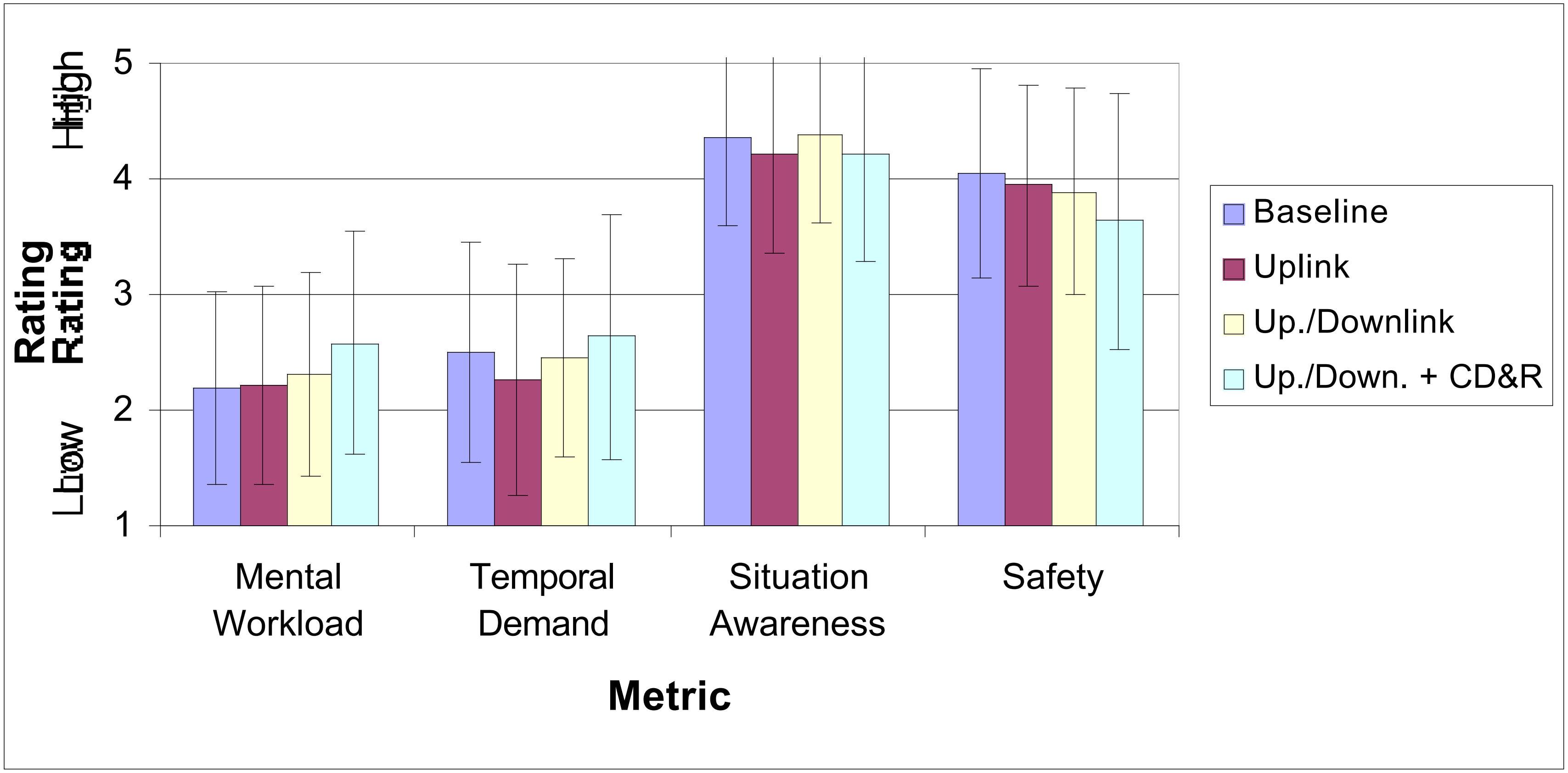
No apparent impact of trajectory negotiation on controller workload

2003 Results: Controller Safety Ratings



No apparent impact of trajectory negotiation on safety

2003 Results: Pilot Post-Run Ratings



No apparent impact of trajectory negotiation on pilot workload, situation awareness, or safety

2003 Results: Pilot-initiated Requests

Negotiation	Condition				Total
	Baseline	Uplink	Uplink/ Downlink	Up./Down. w/ CD&R	
Approved on 1st request	7	6	5	8	**26**
Rejected on the 1st request; uplinked a similar route before the 2nd request	0	0	2	1	**3**
Rejected on 1st request; approved on later request	3	2	0	1	**6**
Rejected Completely	0	1	2	0	**3**

2003 Results: Trajectory Negotiation

- No striking difference between request acceptance via voice vs. CPDLC
  - *Simplicity of the request might have contributed to the similarity*
  - *Trend towards higher acceptance rate for CPDLC-based downlinked requests that are conflict-probed*
- Both controllers and pilots thought that minimum interaction was needed for trajectory negotiation
- Controllers and pilots gave high acceptability ratings for the trajectory negotiation procedures that were used in the simulation
- Interestingly, one controller concern about CPDLC-based requests was that it might be too *easy* to make requests
- Controllers and pilots overwhelmingly supported CPDLC-based transfer-of-communication
- Controllers were as comfortable with CPDLC clearances as with voice, using both depending on context

Conclusions & Recommendations

Results suggest that concept is feasible, and could provide considerable benefits.

- Integration of air and ground automation tools with CPDLC appears extremely promising:
  - Facilitates controller's use of advisories, trial plans and other DSTs
  - Increases proportion of aircraft on stable, predictable trajectories
  - Frees radio for non-routine communications and tactical clearances
  - *Very* well received by both pilots and controllers
  - CPDLC-supported Transfer of Communications especially popular

- Trajectory negotiation itself appears feasible and acceptable, but followup work is needed to:
  - Explore use of automation to manage requests based on controller workload and message urgency
  - Exlore possible benefit scenarios (weather, complex route optimization requests, user-preferred SUA or traffic avoidance)

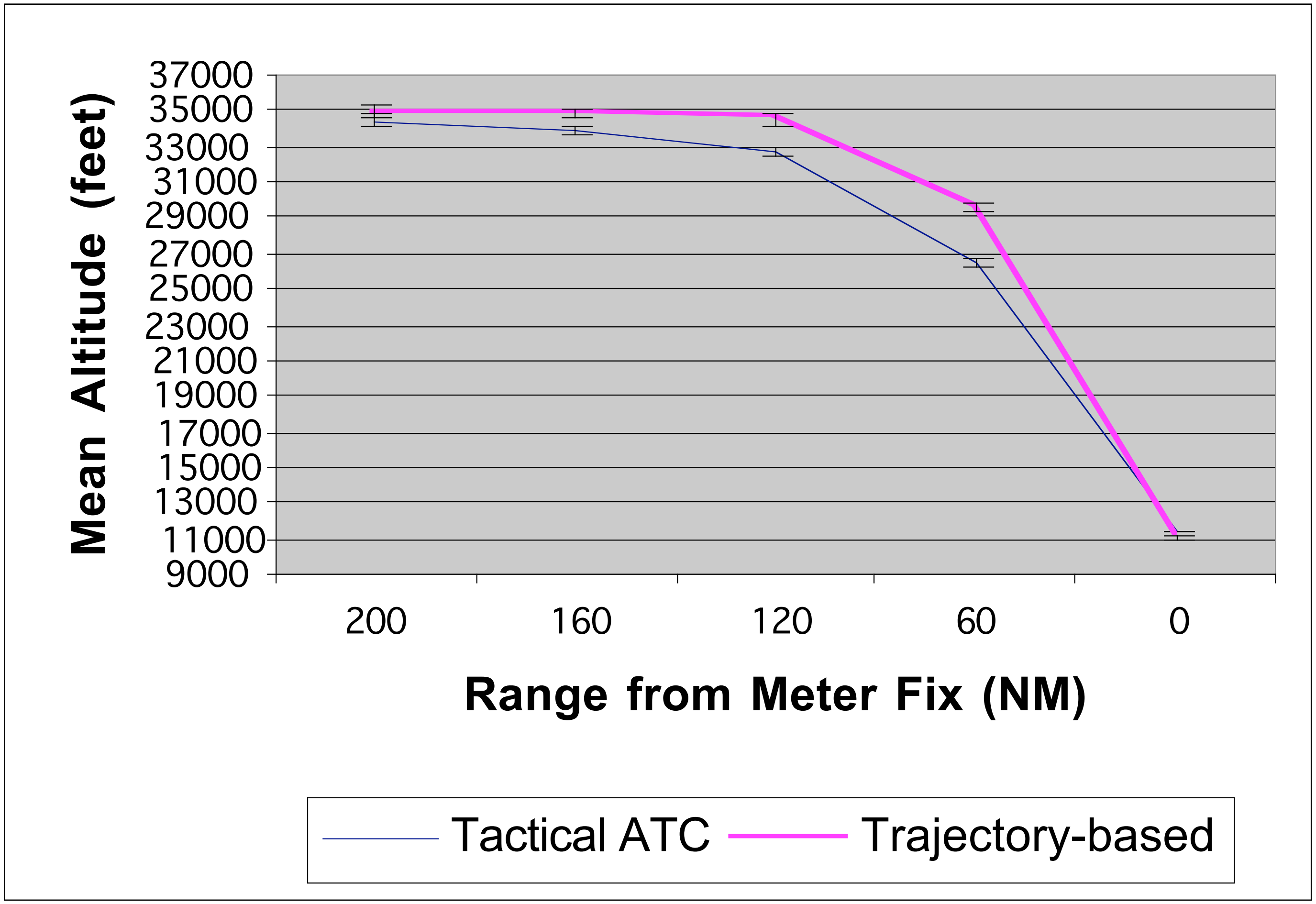
Acknowledgments

- *Sponsors, supporting organizations:*
  - Advanced Air Transportation Technologies (AATT) Program Office
  - Air Line Pilots Association (ALPA)
  - Federal Aviation Administration (FAA)
  - National Air Traffic Controllers Association (NATCA)

- *Staff:*
  - FDDRL and AOL R&D staff
  - Crew-Vehicle Simulation Research Facility (CVSRF) staff
  - “CTO-2” research support from Booz-Allen and Titan Systems
  - Human Factors Division’s facilities support group
  - Cohort staff of “pseudo-” pilots and “confederate” controllers

- *Simulation participants:*
  - DAG-TM pilot and controller team

2002 Results: Mean Altitude of Arriving Aircraft



More aircraft could stay longer at a higher altitude in the trajectory-based condition

2003: Trajectory Negotiation “Probes”

- Overflights:
  1. Aircraft flying northwest path through Ardmore and Amarillo, heading towards west coast requests shorter route that cuts through arrival stream in Falls and Amarillo
  2. Southbound flight in Amarillo for Houston requests direct route to Houston that cuts through Falls sector
  3. Southwest-bound flight through Ardmore and Amarillo requests route to (i.e., heading towards) a different airport, cutting through arrival stream in Falls and Amarillo
- Arrivals:
  4. Arrival through Amarillo and Falls requests ‘en route’ delay prior to the freeze horizon.
  5. Controllers & pilots are alerted to early RTA assignment unusually large delay (e.g., coordinated by AOC with TMU while aircraft is still in Amarillo sector.)